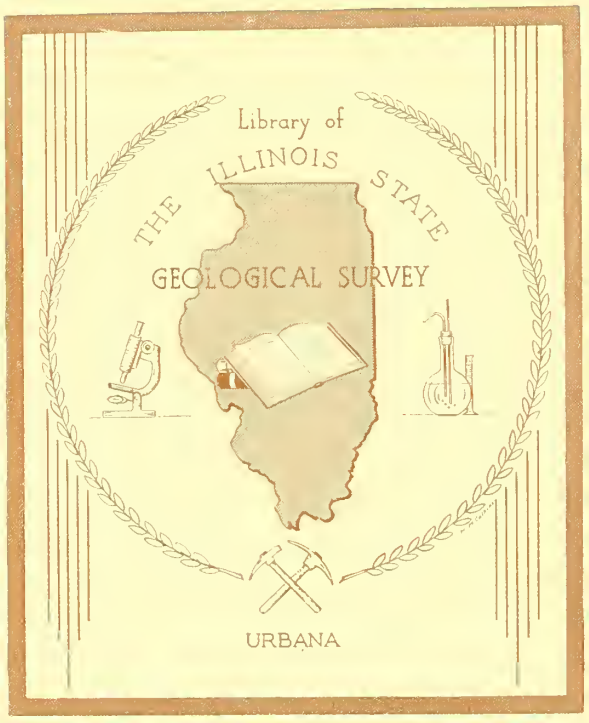
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STUDIES OF LAKE MICHIGAN BOTTOM SEDIMENTS—NUMBER ONE

PRELIMINARY STRATIGRAPHY OF UNCONSOLIDATED SEDIMENTS FROM THE SOUTHWESTERN PART OF LAKE MICHIGAN

D. L. Gross, J. A. Lineback, W. A. White, N. J. Ayer, Charles Collinson (Illinois State Geological Survey) and H. V. Leland (University of Illinois)

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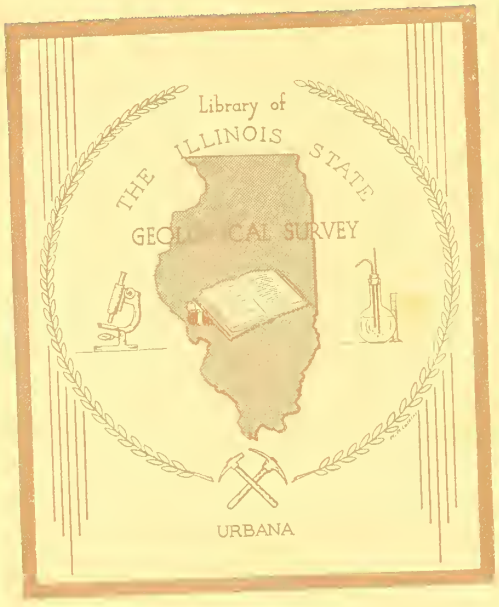
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ABSTRACT

The Illinois State Geological Survey, in cooperation with Dr. Harry V. Leland, University of Illinois, recently began an extensive examination of the unconsolidated sediments of southern Lake Michigan. Sampling was begun in the summer of 1969, and a series of reports will describe the geology and the chemistry of these sediments, with emphasis on their pollution, as measured by lead and other inorganic constituents.

The first report describes lacustrine sediments cored at 4-mile intervals along a line extending from 12 to 32 miles due east from Waukegan, Illinois. The cores illustrate a local stratigraphy for the unconsolidated sediments that floor the southwestern part of Lake Michigan. The sediment sequence includes, from the top, a few centimeters of sandy silty clay on the lake floor; 0.5 to 1.0 meter of dark gray silty clay alternating with thin black clay layers; 0.5 meter of brownish gray silty clay containing thin dark layers; 0.75 meter of orangish brown clay in which there is a traceable gray clay bed 0.15 meter thick; and a homogeneous, pink clay more than 1.0 meter thick that overlies glacial outwash and till. The black layers in the upper part of the cores have yielded a radiocarbon date of 6920 $\pm$200 years B.P. (ISGS 33).

Within the lacustrine sediments, grain size decreases with depth. Water content ranges from 100 percent to more than 200 percent of dry weight. Illite, chlorite, kaolinite, and expandable clay minerals are mixed throughout the cores, although expandables decrease downward and kaolinite decreases upward.

INTRODUCTION

The Illinois State Geological Survey, in cooperation with Dr. Harry V. Leland, University of Illinois, recently began an extensive examination of the unconsolidated sediments of Lake Michigan. Sampling was begun in the summer of 1969 from research vessels of the Great Lakes Research Division of the University of Michigan and the U. S. Bureau of Commercial Fisheries. The Federal Water Pollution Control Administration also furnished samples.

The program has two objectives. The major objective of Dr. Leland and his associates is to determine the extent of dispersal of atmospheric and surface-water pollution in the lake, particularly pollution that can be measured in lead concentration. In the laboratories of the Illinois Geological Survey, this study has been extended to include a wide range of trace elements (Shimp and Leland, in preparation). The second major objective, the particular contribution of the Illinois State Geological Survey, is to describe the areal distribution, stratigraphic sequence, composition, and thickness of unconsolidated sediments under the lake. The nature of the bedrock and the geologic history of the lake will also be studied.

The sampling procedures used in this program and the stratigraphy and composition of the unconsolidated sediments that floor the southwestern part of the lake are described in this report, the first in a series of several such reports planned. Despite the importance of Lake Michigan, relatively few investigations of the type reported here have been made.

ACKNOWLEDGMENTS

We are grateful for the support contributed by several institutions in the form of ship-time and assistance in sample collecting. Sediment cores, water-sediment interface grabs, and water samples were taken from the R. V. INLAND SEAS (Great Lakes Research Division, Ann Arbor, Michigan). Surface-sediment and water samples were collected from the R. V. CISCO (United States Bureau of Commercial Fisheries, Ann Arbor) and the R. V. MYSIS (Great Lakes Research Division). The Federal Water Pollution Control Administration and the Corps of Engineers assisted in sampling nearshore surface sediments.

The cores described in the present report were collected in September, 1969, during a cruise on the R. V. INLAND SEAS. We thank the captain and crew of the R. V. INLAND SEAS for their capable and generously offered assistance in all phases of the sampling operations.

SAMPLING PROGRAM

The Lake Michigan sampling program was carried out on six separate cruises during the summer of 1969. To get good geographic coverage of the lake south of Waukegan, Illinois, and Benton Harbor, Michigan, 144 sampling stations were selected (fig. 1). Sampling intervals were closer near Chicago and near the mouth of major tributaries. This report describes the six cores (numbers 143 to 148) 2 inches in diameter and up to 12 feet long that were

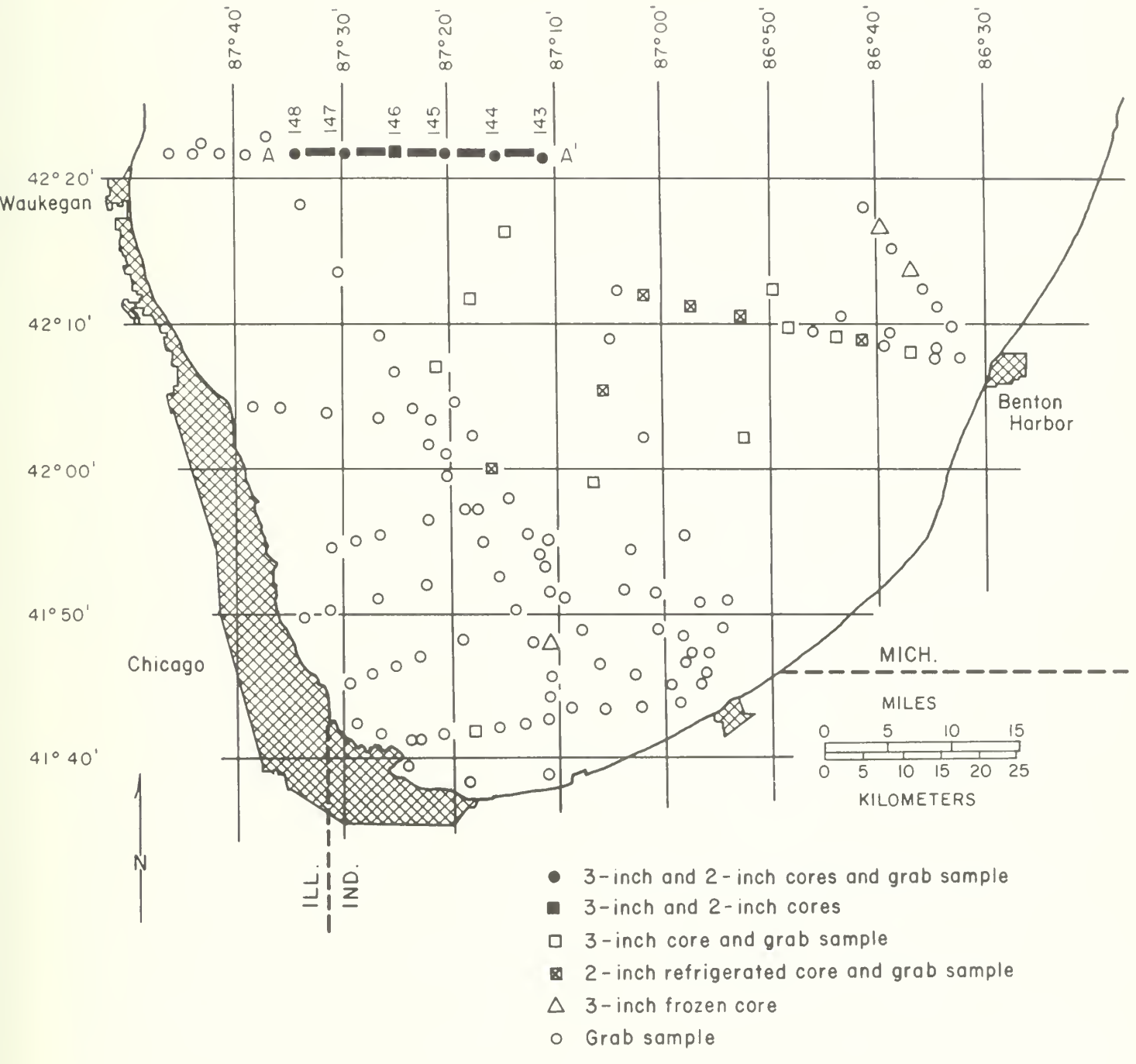


Fig. 1 - Sampling points in southern Lake Michigan, and line of cross section (fig. 3) that includes cores 143 to 148.

collected at 4-mile intervals along a line extending from 12 to 32 miles due east of Waukegan, Illinois (fig. 1). Subsequent publications will describe the other cores collected.

Various techniques were used to obtain water samples, grab samples, and cores of the bottom sediment. Sampling from a large lake or oceanographic vessel requires special skills. Water depths (fig. 2) in southern Lake Michigan exceed 550 feet (168 meters) in places. The sampling device is not visible during most of the sampling operation, and the investigator must rely on instruments and experience to recover reliable samples. An experienced crew on a research vessel, such as the R. V. INLAND SEAS (pl. 1A), can be particularly helpful and can provide additional data in several ways. For example, experienced winch operators glean a surprising amount of information by noting the strain on the winch and by feeling the winch cable.

One factor that increases the difficulty of sampling from a ship is obvious—the vessel is a moving, relatively unstable platform. During unfavorable weather, the complex movement of the vessel becomes a major problem, and frequently lowers sampling efficiency. Additionally, the vessel drifts as a result of the action of lake currents or wind and may cause the coring device to enter the bottom sediments at an angle instead of vertically.

Establishing station locations from a research vessel frequently is difficult, and the farther the vessel is from land, the harder it is to determine station position accurately. The ship was navigated by a combination of visual sighting and radar. The sample locations (fig. 1) are, at best, accurate to within 500 feet. Stations more than 20 miles from shore may be less accurate because the range of the shipboard radar is limited to 20 miles.

Shipek Grab Sampler

The first operation at each station was to obtain a relatively undisturbed sample of the surface sediment with a Shipek bucket (Hydroproducts, Inc., San Diego, Calif.). The sampler consists of a heavy weight that activates a trigger mechanism in a framework containing two powerful springs and a removable sampling bucket. The sampling bucket is a split cylinder with a horizontal major axis. The sampler is suspended over the side of the ship while the sampling bucket is installed (pl. 1B). The device is cocked and lowered to the lake floor. When the sampler reaches bottom, the cable slackens permitting the weight to drop on the framework, thus activating the trigger. The sampling bucket rotates 180° and a sample of the bottom sediment 14 centimeters deep is obtained. The sampler is raised to the deck of the ship and the sampling bucket removed and carried to the ship's wet laboratory. A second sampling bucket can be installed while the first is still in the laboratory.

The Shipek sampler operates satisfactorily in most sediments. It is well sealed after it closes on the bottom and the sample does not appear to be seriously "winnowed" during recovery. Recovery was poor only when we were sampling compacted glacial till, rock, or large gravel. Experience is required to determine the speed the sampler can descend, because if the sampler is lowered too quickly (without applying the brake on the winch) it may trigger before reaching the bottom or it may not descend in the proper vertical position.

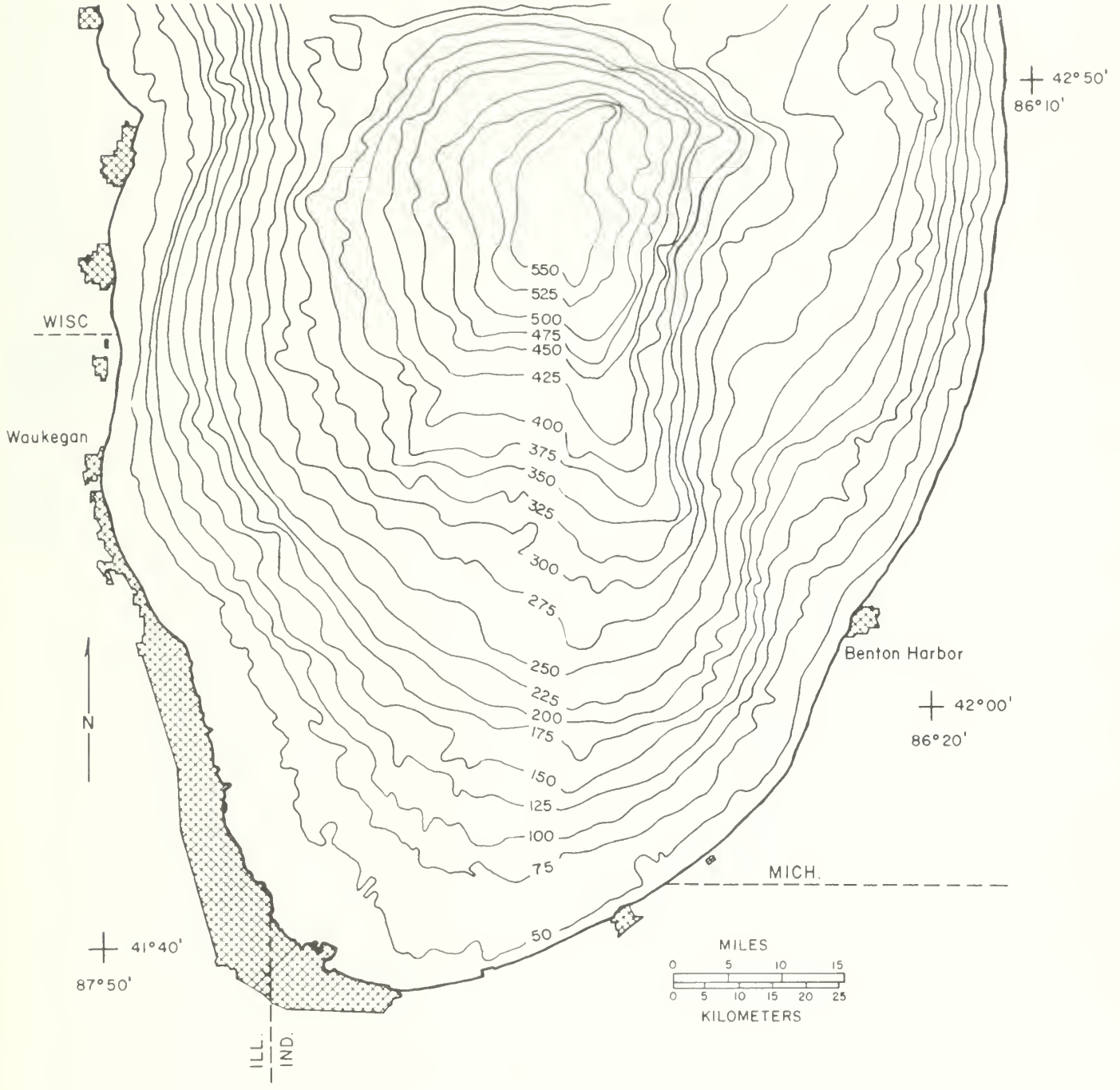
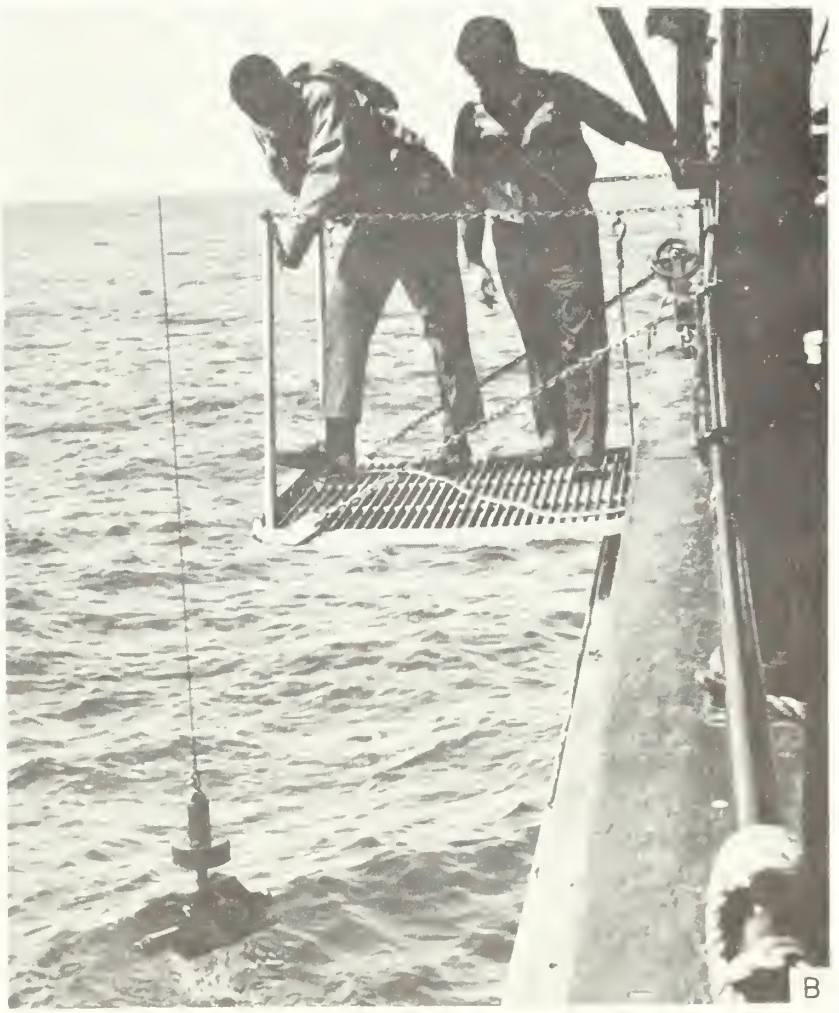


Fig. 2 - Topography of the lake floor, southern Lake Michigan. Contours represent depth in feet below mean low-water level (576.8 feet). Contouring is based on U.S. Army Corps of Engineers Lake Survey District charts.

A - R. V. INLAND SEAS from which most of the coring was done.



B - Shipek grab sampler on the bathythermograph winch and working platform on the side of the R. V. INLAND SEAS.

PLATE I

When the sampler is 10 to 15 feet from the bottom, its descent is slowed and the sampler is lowered gently onto the bottom.

The Shipek was especially valuable for reconnaissance sampling to determine the prospects for successful coring. The sediment sample obtained with the Shipek was examined visually to determine the feasibility of coring at a given locality. Considerable ship operating time was thereby saved by avoiding coring attempts in areas of sandy sediment where the coring device would not penetrate the bottom. The easily removable bucket permitted immediate subsampling of the sediment. Hydrogen ion concentration (pH) and oxidation reduction potential (Eh) measurements of the subsamples were made on board ship and the samples were then frozen for subsequent geochemical analyses (Shimp and Leland, in preparation). A PONAR grab sampler (Wildlife Supply, Saginaw, Michigan), similar to a clamshell bucket, was used for sampling benthic fauna.

Two-Inch Corer

A gravity coring device 2 inches (51 mm) in diameter was designed and built by Dr. J. L. Hough of the Department of Meteorology and Oceanography, University of Michigan, who kindly loaned it to us (pl. 2A). Cores up to 12 feet (3.5 m) long were collected with this device.

The coring device has four principal components: a circular cutting bit on the lower end, a galvanized pipe either 6 or 12 feet (1.8 or 3.6 m) long, a set of weights at the upper end (450 pounds [210 kg] of weights are shown in pl. 2A), and a one-way valve at the top of the core barrel. A core liner of clear cellulose acetate butyrate plastic, 1 7/8 inches (47 mm) inside diameter and 2 inches (51 mm) outside diameter, fits inside the galvanized pipe. The corer is loaded with the plastic liner and the bit placed on the lower end of the barrel while the device is still on the deck of the ship. The corer is lowered to the lake bottom at a winch speed of several feet per second. The device, pushed by the weights on the upper end of the assembly, penetrates the unconsolidated sediments; when the lowering cable has slackened, the corer is raised back to the deck of the ship. The plastic core liner with its sample is removed and a new core liner is inserted in the core barrel for the next sampling. During the lowering, the one-way valve on the top of the barrel is held open by the pressure of water flowing upwards through the liner. Once the lowering is halted and the retrieval operation begins, the one-way valve is closed by water pressure, preventing the sample from washing out of the liner.

The plastic core liner, complete with sediment sample, is sealed with rubber stoppers that are firmly taped in place. If the recovered core does not completely fill the liner with sediment, the excess plastic is cut off before the liner is sealed. The stoppered ends of the core liner are coated with Baveco Victory Brown 155 wax to prevent water loss. Through the clear plastic of the core liner, the entire sediment column is visible and a preliminary stratigraphic description is commonly made in a matter of minutes so that the best sampling procedure for the next sampling station can be decided while the ship is traveling to that location.

The cores were transported to Urbana and stored in a room having a constant temperature of 5° C, a temperature similar to that at the bottom of Lake Michigan, to retard bacterial growth in the cored sediment. While still in the plastic core liners, the cores were radiographed. For study in the laboratory the cores were extruded from the plastic liners by a plunger and ramrod.

After being extruded, the cores were divided lengthwise and photographed in color. An extremely detailed visual description was made before the subsampling of the cores. Many closely spaced samples were analyzed for water content, grain size, clay mineralogy, fossil content, chemical composition, and engineering properties. A thin slice of the core was allowed to dry in the open air and was visually examined for microfossils.

Three-Inch Corer

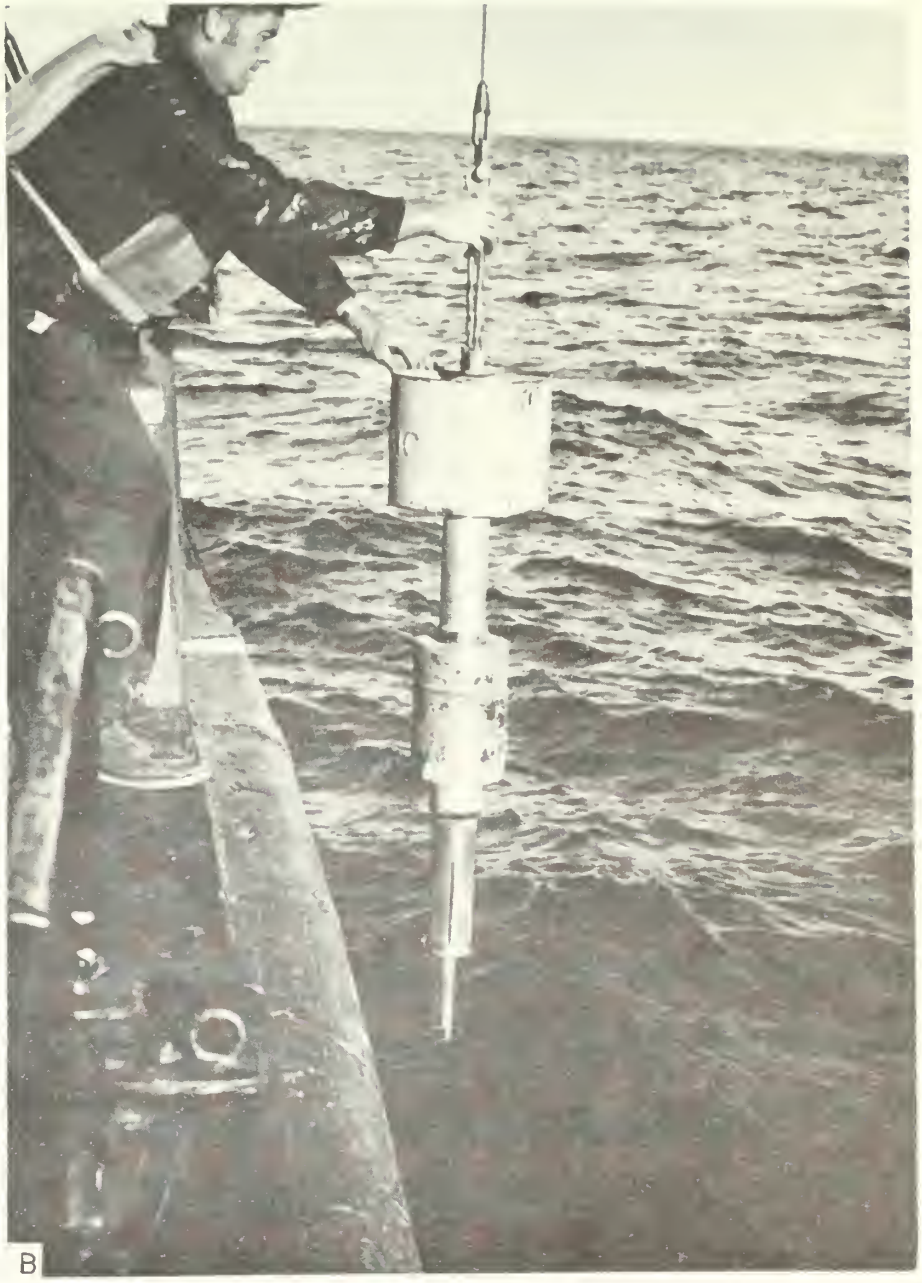
Another type of coring device, manufactured by Benthos Inc., Falmouth, Mass., was used to collect samples 2 5/8 inches (67 mm) in diameter and up to 4 feet (1.2 m) long (pl. 2B). The Benthos corer is a gravity corer and works very much like the 2-inch corer just described. The Benthos corer, however, does not have an external steel barrel, so the plastic core liner (outside diameter 2 7/8 inches [73 mm]) is unsupported. As a result, the samples collected by this device show less disturbance because the core barrel has thin walls and the internal diameter of the liner is larger. The core length is limited by the strength of the unsupported plastic liner.

A one-way valve at the top of the Benthos corer is activated by a spring and sealed with an O-ring gasket. After the corer has penetrated the bottom sediments, the slackening of the lowering cable activates a trigger mechanism to seal the valve. It is thus possible to collect relatively undisturbed samples of the upper few centimeters of bottom sediment.

Most of the samples collected with the 3-inch corer were used for chemical and radiocarbon analyses, whereas the samples collected with the 2-inch corer were used for stratigraphic work. The 3-inch cores were frozen on board ship and have been stored in a -20° C cold storage room in Urbana. Freezing serves two purposes—it prevents mechanical mixing of the very fluid upper few centimeters of sediment, and it inhibits biologic activity inside the core, which might otherwise affect the reliability of radiocarbon dates.

In the laboratory, the frozen cores were freed from the plastic core liner by warming it in hot water and then sliding the cylinder of frozen sediment out. The frozen core was notched with a clean hacksaw and was cleaved into the desired subsamples. Some of these samples were analyzed for chemical composition and grain size, and the results will be reported by Shimp and Leland (in preparation).

A - Two-inch diameter and 12-foot long coring device on the heavy winch of the R. V. INLAND SEAS.



B - Benthos coring device on the heavy winch of the R. V. INLAND SEAS.

PLATE II

STRATIGRAPHY

Introduction

Hough (1958) wrote a comprehensive summary of the geology and history of the Great Lakes. Bottom sediments in southern Lake Michigan have been studied by Hough (1935), Ayers and Hough (1964), Davis and McGeary (1965), Ayers (1967), and Sommers and Josephson (1968). The present report describes the composition and stratigraphy of the upper 12 feet (3.66 m) of sediment.

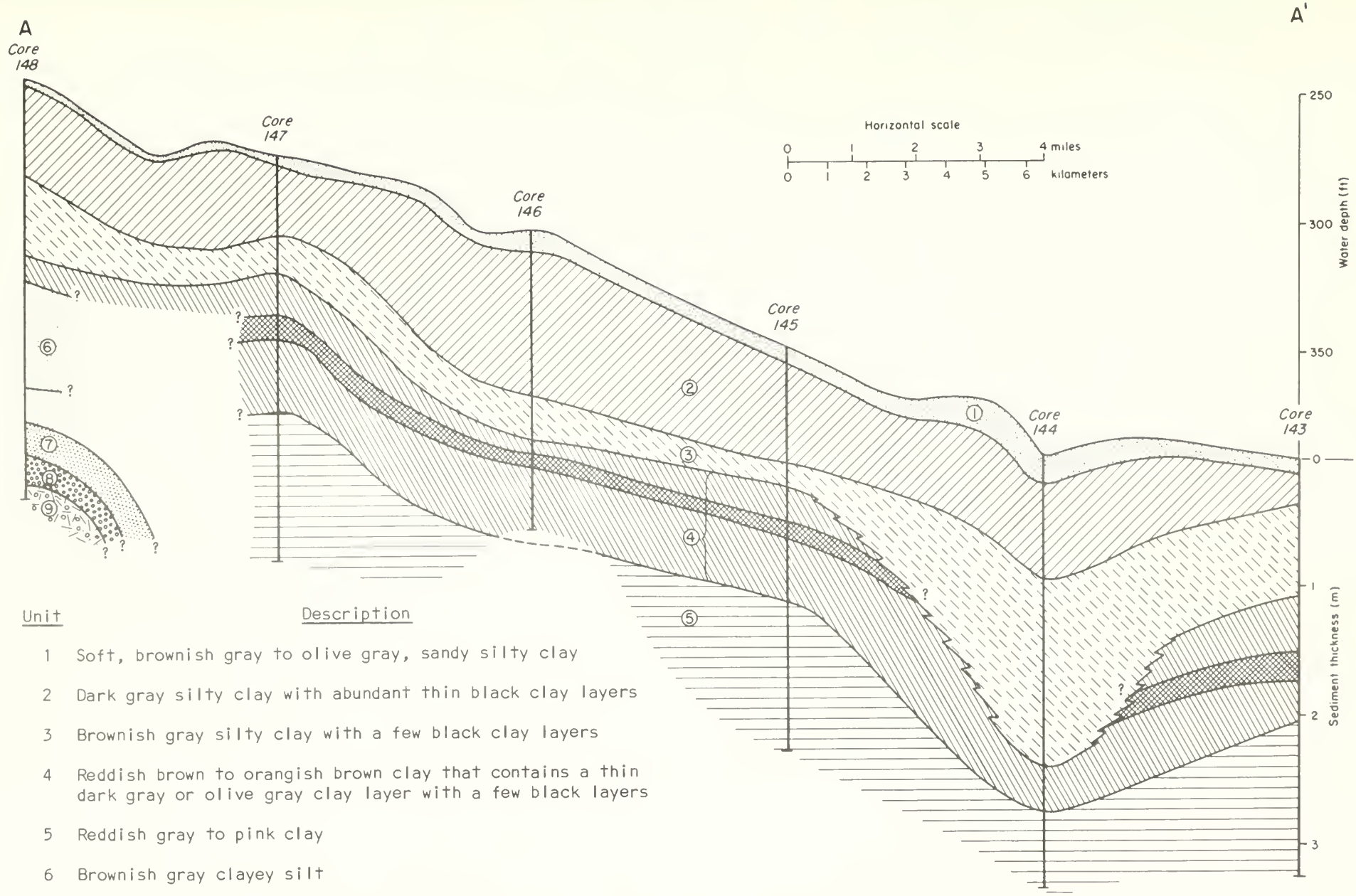
The bedrock floor of southwestern Lake Michigan is overlain by an irregular thickness of glacial deposits, including till and outwash. The glacial deposits, in turn, are overlain by lacustrine sediments ranging from nearly pure clay to sandy silts and, locally, to sand and gravel. The total thickness of the sediments above bedrock is unknown for much of the lake and awaits further coring and geophysical work. Bedrock coring and geophysical profiling done offshore near Chicago for Harza Engineering Company for the City of Chicago indicates that unconsolidated sediment varies from 0 to at least 125 feet (38.1 m) in the southwestern part of the lake. Clausen (1917) reported up to 80 feet (26.5 m) of unconsolidated sediment over the Wilson Avenue water intake tunnel, which extends for 3 miles east of Chicago. This range of thickness in sediment may be typical in the lake basin.

Units Described

Six cores (143-148) 2 inches in diameter, taken along a line extending from 12 to 32 miles due east of Waukegan, Illinois, were studied in detail (figs. 2, 3). Unconsolidated sediments include glacial till and outwash and clayey lacustrine deposits. Glacial deposits were penetrated only in the core nearest to shore (148). The remaining cores consisted entirely of lacustrine sediments and show vertical variation in color that can be correlated from core to core. The color of the lacustrine sediments ranges from dark gray near the surface to brownish gray, brownish red, and pinkish gray downward. Water content differs vertically according to stratigraphic unit. Particle size decreases downward from 50 percent clay at the surface to more than 90 percent clay at depth. Expandable clay minerals, including vermiculite, decrease in abundance with depth whereas kaolinite increases. Illite and chlorite contents remain more or less constant but show less variability with depth. Carbonates are found only in the upper sediments, and the calcite content generally exceeds that of dolomite.

Unit 1

The top 5 to 20 centimeters (2 to 8 in.) of unconsolidated sandy silty clay is generally very soft and quite fluid (unit 1, fig. 3). Water content is near 200 percent of dry weight and clay content is about 50 percent. This unit is brownish gray to olive gray. Because of its softness, the surface unit is often disturbed during coring.



Unit	Description
1	Soft, brownish gray to olive gray, sandy silty clay
2	Dark gray silty clay with abundant thin black clay layers
3	Brownish gray silty clay with a few black clay layers
4	Reddish brown to orangish brown clay that contains a thin dark gray or olive gray clay layer with a few black layers
5	Reddish gray to pink clay
6	Brownish gray clayey silt
7	Brownish gray sandy silt
8	Brownish gray clay-pebble conglomerate
9	Brownish gray, sandy clay till

Fig. 3 - Cross section of the unconsolidated sediments east of Waukegan, Illinois. Location shown on figure 1.

Unit 2

The surficial silty clay unit is underlain by a dark gray silty clay that contains an abundance of thin (1 to 2 mm) layers of black clay containing some organic matter (unit 2, fig. 3). Black mottling is also present throughout most of the dark gray clay of this unit. The unit ranges between 25 and 110 centimeters (10 and 43 in.) thick. Dark gray clay between the black layers is faintly laminated with alternating thin beds of slightly lighter and darker gray clay. Unit 2 is firmer and more cohesive than the surface unit. Water content of the dark gray clay ranges between 100 and 150 percent of dry weight, and the unit averages 55 to 60 percent clay.

The black clay layers were removed from the dark gray clay unit of core 146 and provided sufficient organic carbon for radiocarbon dating. A date of 6920 $\pm$200 years B.P. (ISGS-33) was determined by Stephen Kim in the laboratories of the Illinois State Geological Survey and provides an average date for the sediments lying between 26 and 106 centimeters (10 to 42 in.) in core 146. The sediments below the dark gray clay are older than 7000 years B.P.

Unit 3

The dark gray silty clay of unit 2 is underlain by brownish gray silty clay that also contains thin black clay layers, but they are fewer in number than in the dark gray clay. The brownish gray clay (unit 3, fig. 3) ranges between 25 and 145 centimeters (10 and 57 in.) thick and has a water content between 90 and 125 percent of dry weight. Clay content is 50 to 60 percent, and this is the lowermost unit to contain significant amounts of sand (up to 10 percent). Unit 3 is anomalously thick in core 144, where it apparently occupies a channel cutting into the underlying unit (fig. 3). At this station the brownish gray clay contains many thin layers of dark gray to black clay.

The three units just described occur in their entirety in all six cores taken off Waukegan. The underlying lacustrine units are present in most cores, but in some they either do not occur or they were not penetrated. Below unit 3 the color and nature of the sediments change markedly. Black layers are scarce, the sediment is more clay rich, kaolinite appears, and the amount of expandable clay minerals, including vermiculite, decreases.

Unit 4

Underlying the brownish gray clay is an orangish brown to reddish brown clay (unit 4, fig. 3). Parts of this unit are present in all six cores. Where the whole unit is present, it ranges between 85 and 110 centimeters (33 and 43 in.) thick. Clay content is 80 to 90 percent and expandable clay mineral content somewhat lower than in overlying units. Black layers and mottling are virtually absent from the reddish brown clay.

In four of the cores unit 4 contains a thin, 10- to 20-centimeter (4 to 8-in.) layer of dark gray or dark olive gray clay. This dark gray clay bed closely resembles the dark gray silty clay of unit 2, discussed above.

It contains black layers and mottling and a trace of sand that is absent from the reddish brown clay enclosing the unit. In addition, like the higher dark gray clay and unlike the reddish brown clay, the thin dark gray clay has no kaolinite. Water content of the reddish brown clay ranges from an average of 100 percent of dry weight at the top of the unit to an average of 200 percent at the top of the dark gray clay layer, with some samples as high as 220 percent.

Unit 5

Underlying the reddish brown clay is a reddish gray to pink clay (unit 5, fig. 3). The thickest penetration of this unit is 120 centimeters (47 in.), and it is the lowermost unit penetrated in four of the cores. The reddish gray clay averages over 90 percent clay and is generally massive and homogeneous, although faint color banding may be present. Expandable clay minerals are scarce in this unit but kaolinite is at its greatest abundance. Water content decreases from 200 percent of dry weight at the top of the unit to 150 percent at the 100-centimeter (39-in.) depth.

Unit 6

Core 148 penetrated 20 centimeters (8 in.) of reddish brown clay (unit 4) and then 110 centimeters (43 in.) of brownish gray, clayey lacustrine silt overlying glacial deposits (unit 6, fig. 3). The brownish gray silt may correlate in part with the reddish brown and reddish gray clays of the stations farther offshore, but the correlations are problematical.

Units 7, 8, 9

Core 148 also penetrated 60 centimeters (24 in.) of glacial deposits, which can be divided into three units, all brownish gray. The first glacial unit penetrated is 24 centimeters (9.5 in.) thick and consists of two sandy silt subunits, each grading downward from coarse silt to fine sand (unit 7, fig. 3). The next unit is 24 centimeters (9.5 in.) of clay-pebble conglomerate (unit 8, fig. 3). The pebbles are gray to brownish gray, many of different shades than the matrix. The largest pebble is about 1 centimeter in diameter. The lowermost unit, presumably the oldest sediment penetrated in the six cores, is 12 centimeters (5 in.) of sandy clay till (unit 9, fig. 3). The till is soft, but much firmer and more compact than the lacustrine deposits. The till contains clay pebbles and angular rock fragments.

LABORATORY RESULTS

Radiography of Unopened Sediment Cores

Cored sediment recovered from Lake Michigan has very low shear strength and high water content and is consequently quite susceptible to disturbance. Much of the sediment appears to be relatively featureless as well.

To evaluate sediment disturbance due to coring techniques and to determine whether the material was in fact featureless, a series of radiographs is being made on equipment belonging to the Department of Geology, University of Illinois. The equipment consists of a Picker Gemini-160 X-ray unit, which automatically maintains a constant peak potential and is equipped with a Morris beryllium-window X-ray tube. Kodak Type M Industrial X-ray film (4 1/2 by 17 in.) is used and is processed in a Calumet nitrogen-burst processor. Optimum exposure for the cores of 2-inch diameter is 60 kilovolts at 10 milliamperes for 105 seconds. At this exposure, the developed image is somewhat darker than an acceptable photographic negative, but it can be examined easily with moderate illumination. Selected core segments are radiographed stereoscopically (Ayer and Richards, 1967). In this technique, the core tube is rotated approximately 10 degrees about its long axis between exposures on separate sheets of film. The developed images may be viewed stereoscopically. This method is useful for examining the three-dimensional relations between rock fragments in cored glacial till.

Careful examination of radiographs indicates minimal deformation due to coring. Most cores contain a few shear faults, indicating that some vertical compression of the sediment occurred during coring.

Details visible in radiographs, such as larger fossils, rock fragments, and soft clay pebbles, are used to help determine which core segments are to undergo specific analyses. A radiograph of a frozen core 3 inches in diameter showed that freezing the core had intensely shattered the sediment, resulting in a partial loss of stratigraphic information. Examination of the radiographs has disclosed zones of possible root systems within the cores, which may have implications as to past lake-surface levels. Cored intervals that appeared to be featureless to the eye were shown to contain clearly defined layering and occasional rock and clay fragments. The radiographs also constitute a permanent record of internal structural relations to supplement photographs and visual core descriptions.

Radiocarbon Dating

The radiocarbon date of 6920 $\pm$200 years B.P. (ISGS-33) from black layers of the dark gray silty clay (unit 2) in core 146 is significant for several reasons. It is the first radiocarbon date from Lake Michigan lacustrine sediments. It also indicates that sedimentation in Lake Michigan has been rather slow for the past 7000 years because the dated interval (26 to 106 cm) is near the top of the core. Since the date is an average, we can infer that less than the uppermost meter of sediment was deposited in the last 7000 years. The date of the last glacier to occupy the southern part of the Lake Michigan Basin is unknown, but it is later than the youngest tills around the southern margin of the lake, which have been dated at about 13,000 years B.P. In the northern part of the lake basin a glacier was present at least as late as 11,500 radiocarbon years B.P. More than 2 meters of sediment must therefore have been deposited at the location of core 146 during the first 6000 years after deglaciation and less than 1 meter in the last 7000 years.

Clay Mineralogy

X-ray diffraction analyses of the clay-size fraction (<2 microns) from closely spaced samples show vertical changes in the mineralogy of the sediment (figs. 4, 5, and 6). The proportions of the clay minerals are determined from ratios of diffraction effects and are not considered as percentages. When the Lake Michigan core samples were X-rayed, the area under the peaks of the diffractograms proved to be smaller than the underpeak areas displayed by samples of similar mineralogy that had been taken from bedrock clays and shales in Illinois. Because the Lake Michigan samples give smaller underpeak areas, we assume that some of the material is not sufficiently crystalline to produce discernible diffraction effects and is therefore called amorphous.

The clay minerals determined from the diffraction effects include illite, chlorite, kaolinite, and expandable clay minerals. The expandable clay minerals can be expanded with glycol or can be collapsed by heating them to 350° C for 1 hour. These clay minerals are mixtures of montmorillonite and chlorite, vermiculite and chlorite, mica and chlorite, or any such combination of the three minerals. Where possible, the expandable clay minerals were divided into vermiculite, montmorillonite,and "other."

Nonclay minerals were also determined by diffraction, among them potash and plagioclase feldspar, amphibole, quartz, dolomite, and calcite.

The most noticeable vertical change in clay mineralogy is that the relative amounts of expandable clay minerals, including vermiculite, decrease downward (figs. 4, 5, 6). Kaolinite is absent above the lower part of the brownish gray clay (unit 3). Illite and chlorite remain fairly constant throughout, but they vary less in the lower part.

Water Content and Grain Size

Water content of cores 145, 146, and 148 ranges from about 100 to 200 percent of dry weight (figs. 4, 5, 6). Particle size for these cores was determined by a combined sieving and pipette analysis after disaggregation of the samples previously used to determine water content. The upper few centimeters of silty clay is quite fluid, with water content near 200 percent. Clay content increases downward in cores 145 and 146 (figs. 4, 5). Water content is relatively low in the silty clay sediment of the upper 100 to 150 centimeters (39 to 59 in.) but increases in the more clayey lower parts of the core. In core 145 (fig. 4), water content in the lower clay units (units 4 and 5) decreases with increasing depth, perhaps because of compaction. Core 148 is very silty because it was taken close to shore (fig. 6). Below the depth of 50 centimeters in core 148 (fig. 6), the water content decreases with depth. Core 146 was taken nearer shore than 145 and shows somewhat more silt in some units. Increasing distance from land-derived sources of coarse material and from nearshore reworking by waves accounts for the offshore increase in clay content. The downward increase in clay noted in cores 145 and 146 may result from the probable rock-flour origin of the clay-rich units.

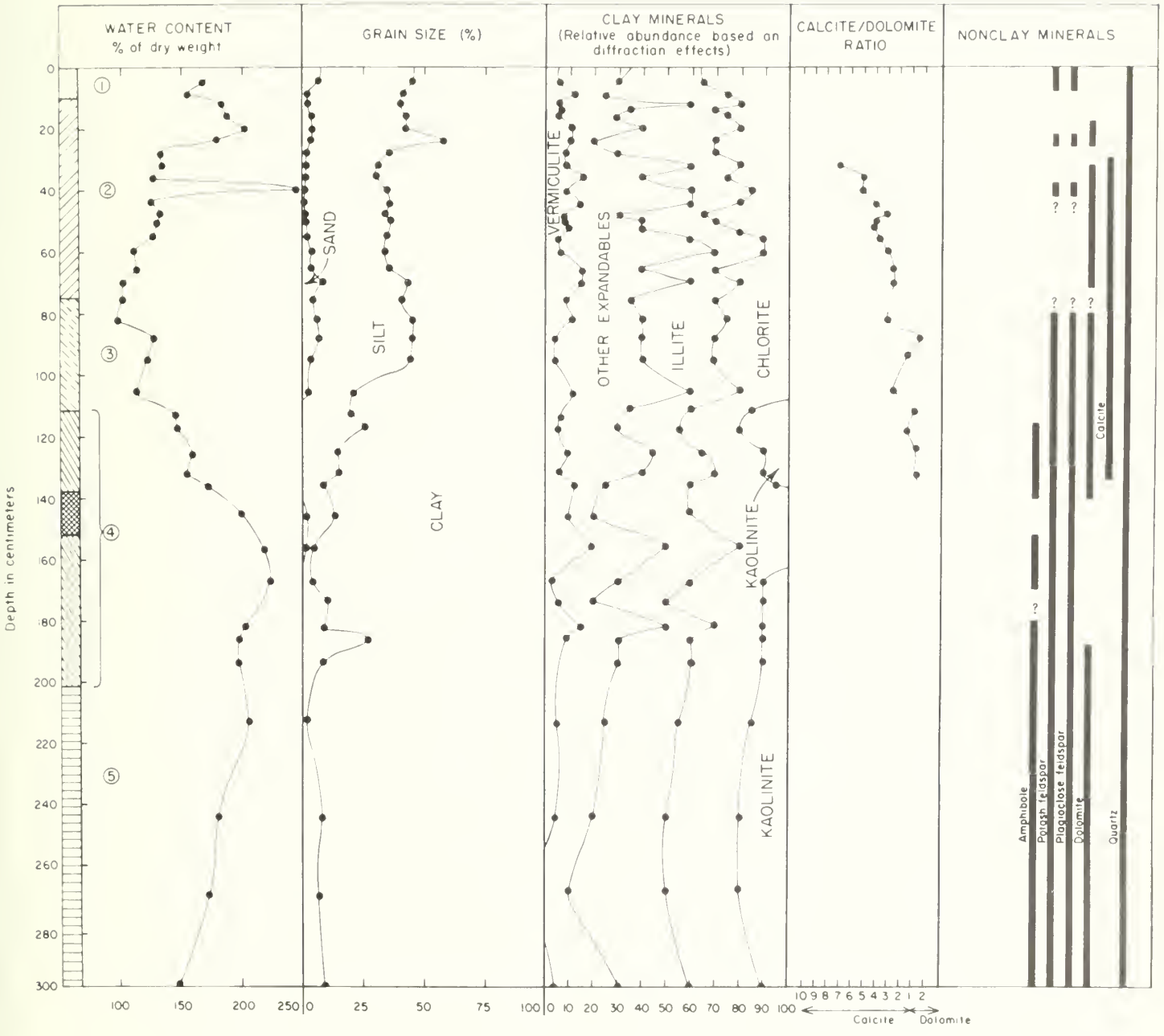


Fig. 4 - Grain size and mineralogy of core 145.

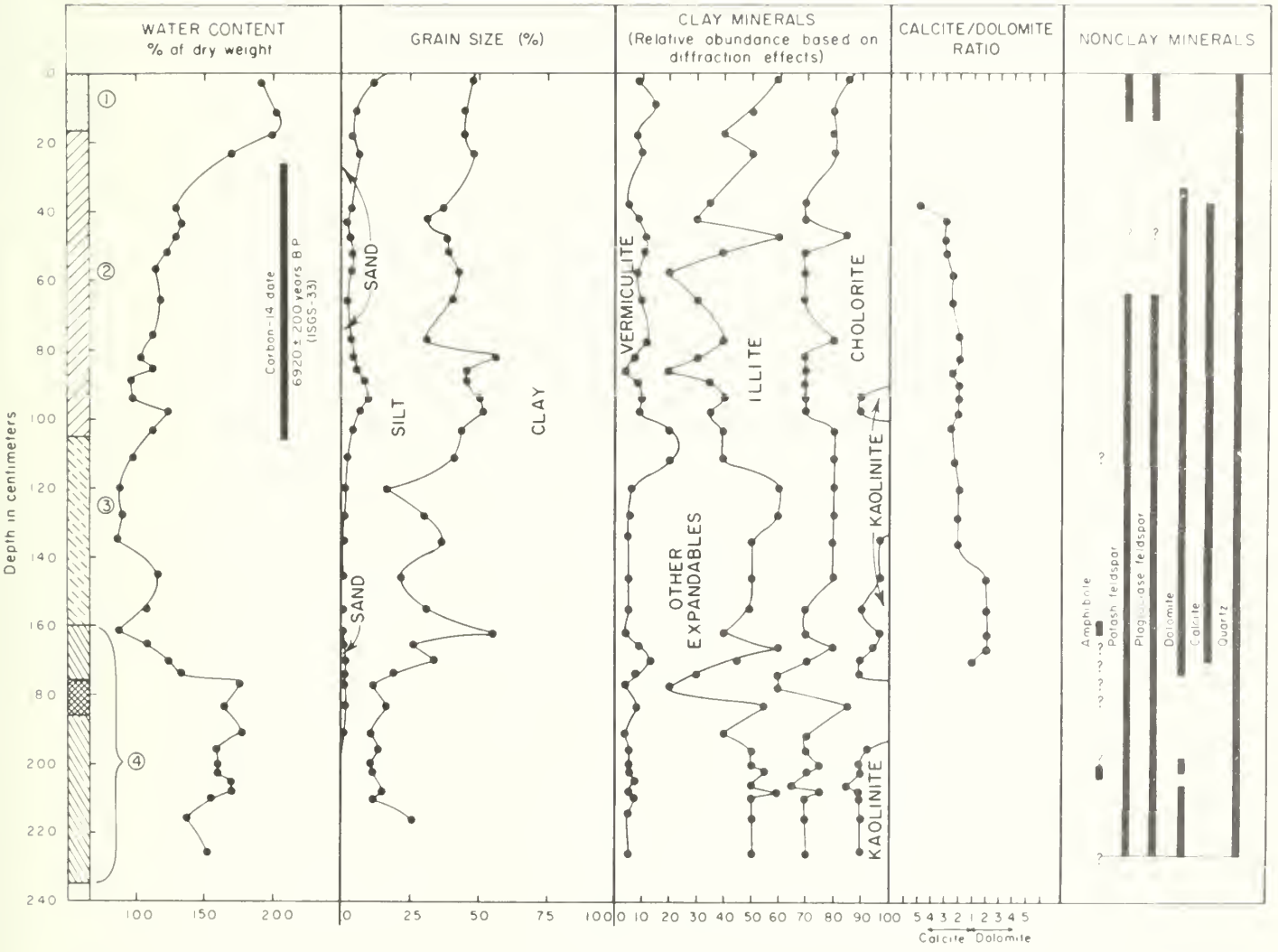


Fig. 5 - Grain size and mineralogy of core 146.

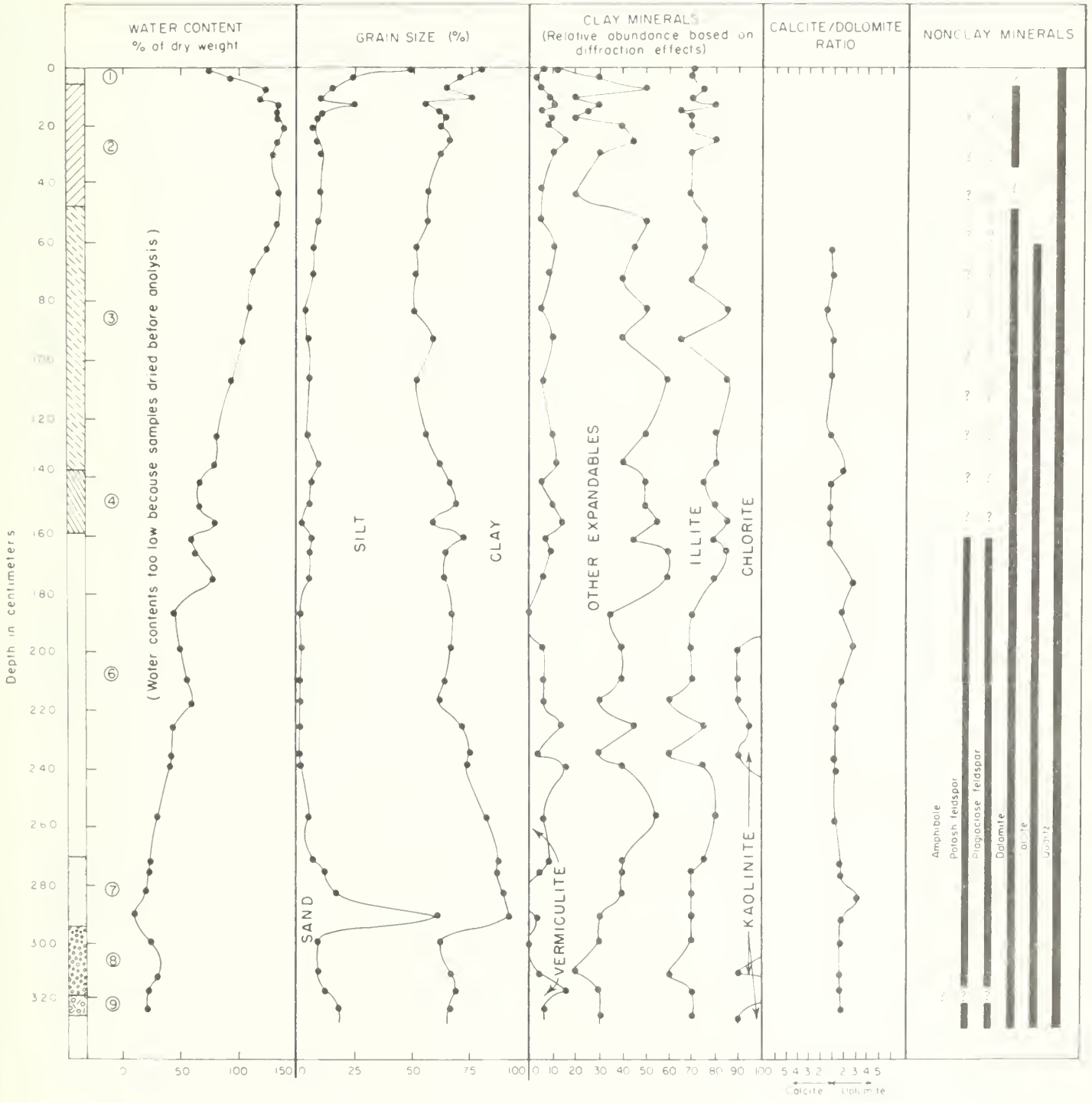


Fig. 6 - Grain size and mineralogy of core 148.

Engineering Properties

Measurement of the engineering properties of the sediments was not one of the prime objectives of the project, but a few observations were made. The sediments are extremely soft and have very high water contents. The original water contents of the lacustrine sediments range from 100 to 200 percent of dry weight (figs. 4 and 5). The lacustrine sediments have a very low shear strength and are thixotropic. A torvane shear-strength instrument was used in the upper part of core 145, but the shear strength of the sediment was less than the sensitivity of the instrument (less than 0.2 tons per square foot). At the base of the lacustrine sequence, measurements as high as 0.3 to 0.4 tons per square foot were found. Atterberg limits of the pink lacustrine clay in core 145 had an average liquid limit of 90 percent and an average plastic limit of 31 percent. The natural water content of this sediment was 172 percent of dry weight, considerably over the liquid limit of 90 percent and probably near the fluidity limit (White, 1955). (Fluidity limit is the moisture content, expressed as a percentage by weight of the oven-dried clay or soil, at which the clay or soil will begin to flow with one tap on the liquid limit machine.) It is evidently only because of their thixotropic character that the sediments are reasonably cohesive when extruded from the core liner.

Chemical Composition

Chemical analyses of sediment cores, including some of the cores reported here, are being made in the laboratories of the Illinois State Geological Survey. The results of the chemical study will be presented in a forthcoming Environmental Geology Note (Shimp and Leland, in preparation).

DISCUSSION

The Illinois State Geological Survey, in conjunction with the University of Illinois, has undertaken a many-faceted study of southern Lake Michigan. Sediment cores and bottom samples from stations in southern Lake Michigan have revealed some preliminary information on the nature of the bottom sediment and its stratigraphy. Shimp and Leland (in preparation) will report on the chemistry of the lake sediments.

Several geologic publications describing the other cores and grab samples shown in figure 1 will be forthcoming. The Illinois State Geological Survey anticipates that its future geologic work on Lake Michigan will include:

1. More and deeper sediment cores for stratigraphic studies of lake bottom sediments.
2. Preparation of maps showing distribution and character of bottom sediments.
3. Study of till samples from the lake bottom to determine their relation to lake shore tills and to help develop a sedimentological history of the lake.
4. A geophysical program to determine thickness of unconsolidated sediments, their stratigraphy if possible, and the topography of the bedrock surface.
5. Determination of bedrock stratigraphy by geophysical means and the preparation of bedrock geologic maps.

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